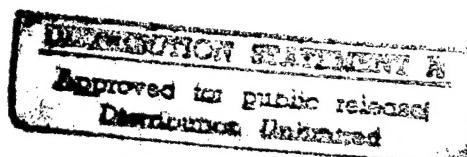


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A PILOT FIELD TRIAL
TO COLLECT HUMAN
PERFORMANCE DATA AT SEA

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Executive Summary

Motion sickness is a constant threat to the operational effectiveness of naval vessels; therefore Canada has a strong interest in the design and construction of warships which can operate under various - and sometimes extreme - sea states, without a high level of motion sickness. To provide some additional insight into cognitive performance in the ship-motion environment, the Defence and Civil Institute of Environmental Medicine participated in a research sea-trial organized by the Defence Research Establishment Atlantic, using the research vessel Quest. From the perspective of human performance research, the purpose of this study was largely a pilot project to assess the feasibility of various types of human performance experimentation at sea. As a result, the majority of this report has a "lessons learned" flavour, which will be of importance in the planning of future sea trials. A rudimentary look at the data collected indicates that the measures can vary significantly (20% variation in mean fraction correct observed); however, the interpretation of the variation is unclear. It is recommended that the cognitive test battery used in this sea trial be used in a subsequent, formal study of the effects of ship motion on human performance.

A Pilot Field Trial to Collect Human Performance Data at Sea

by A. Hawton and I. Mack
(in alphabetical order)

Introduction

Current and future warships are highly automated and require crews to make accurate and consistent judgments under time pressure. Motion sickness is a constant threat to the operational effectiveness of naval vessels. Therefore, Canada has a strong interest in the design and construction of warships which can operate under various - and sometimes extreme - sea states, without a high level of motion sickness. Ship design has developed to the point where ship motion can be predicted in advance. Understanding of human response to ship motion has not advanced.

One means of measuring human response to ship motion is the use of Motion Sickness Incidence (MSI), which is defined as "the percentage of a population who vomit when exposed to provocative motions" (Colwell, 1994). MSI has become an accepted standard among the ABCD (American-British-Canadian-Dutch) nations (ABCD, 1995), and "... will replace (for some operations) that of vertical acceleration, which was derived as a single number independent of the frequency of motion." (*Ibid*, p.1).

MSI provides a relatively simple measure of human performance at sea, which is human-centred, rather than equipment-centred. However, some important questions cannot be addressed by the use of MSI. For example, does performance degrade significantly at motion levels which do not produce vomiting? Furthermore, it has been observed (Colwell, 1994) that MSI decreases with continuous exposure at sea. Thus, while vomiting may be reduced, the question - how does cognitive performance compare over time - remains unanswered.

To provide some additional insight into cognitive performance in the ship-motion environment, the Defence and Civil Institute of Environmental Medicine participated in a research sea-trial organized by the Defence Research Establishment, Atlantic, using the research vessel Quest. The Quest is a Canadian Forces Auxiliary Vessel with a displacement of 2130 tonnes, length = 71.6m and breadth = 12.8 m. A transverse, flume-tank roll stabilization system was in use throughout the cruise.

Method

The research facilities aboard the Quest during the twelve-day cruise were shared between DCIEM, the DREA Hydronautics Section (human performance research) and the DREA Sonar Division (underwater acoustics research). Experiments for both sections were conducted while in transit from Halifax to and from a point approximately 500 nautical miles south. No port stops were made.

The human performance experiments consisted of static and dynamic tests of postural stability; a cognitive test battery; a test of hand/eye coordination; a visual search task; a paper and pencil questionnaire (the PAQ); and a computer-based questionnaire with similar content to the paper version. Only results from the cognitive test battery will be discussed in this report (questionnaire results will be analysed by DREA). Subjects for these experiments were drawn from the fifteen members of the scientific staff on board (six in human performance, nine in underwater acoustics); and members of the ship's company which consisted of twelve officers and twenty-two crew. Everyone was encouraged to participate in one session from each of the experiments per day, depending upon the time constraints of their regular duties.

Days one and eleven of the cruise were used for the set up/tear down of the labs and equipment, which left a total of nine days in which to gather data. The cognitive test battery was administered on a MicroSlate PC with a touch screen, which was set up in lab space located at the aft end of the deck house, on the starboard side. The computer was taped down to a table which was bolted to the floor, to reduce the interference of ship motion on the subjects responses.

A motion sensor which detected variations in the ship's pitch, roll, and vertical acceleration, was located beside the computer during days seven through eleven. Prior

to this, the motion sensor was in the forward lab where the static tests of postural stability were being conducted. The ship motion sensor samples and records ship motion at a collection rate of approximately 5Hz. Reduced data provided to DCIEM for analysis consisted of RMS-averages over periods of approximately 30 minutes duration. The device is not capable of measuring motion frequencies directly, but with some effort frequencies may be inferred from the sampled data, by identifying changes in the direction of acceleration.

Twenty-six subjects completed between three and nine sessions of the cognitive task battery (twelve scientific staff, four ships officers, ten crew). Each session consisted of two minutes of each of three tasks: a short term memory task (STM), a serial reaction time task (SRT; Wilkinson and Houghton, 1975), and a logical reasoning task (LRT; Baddeley, 1968).

The short term memory task requires the subject to observe a series of digits being presented sequentially on the screen, and to enter the numbers in either forward or backward order, depending on an instruction given by the computer. The difficulty of the task increases by one digit each time the subject gives a correct response, and decreases by one number for each incorrect response.

During the serial reaction time task four buttons, numbered '1' '2' '3' and '4' are presented on the screen. One of the four numbers appears above the on-screen buttons (in the same full-sized window), and the subject must respond by touching the button corresponding to that number. As soon as a response has been made the target number changes and the subject continues as quickly and accurately as possible. Response times are recorded from the appearance of the target letter to when the subject makes his response.

In the LRT task, the letters "A" and "B" are presented together with either "A" or "B" first, i.e. "AB" or "BA". Then a statement is presented which includes the two letters and a logical relation between them, e.g. "B does not precede A". There are a total of eight possible relations. The presentation order of "A" and "B" and the relations is selected randomly. The correct response is either "TRUE" if the relation statement correctly describes the presented pair, or "FALSE" otherwise.

Results

There were a number of data collection difficulties inherent in this sea trial which call into question, *a priori*, the validity of any data analyses. Nevertheless, in order to complete the assessment of this pilot study, some results were analyzed. Of the three primary cognitive tasks - STM, SRT, and LRT - the latter was selected for an example analysis.

Vertical acceleration was selected as the independent variable. Analysis of variance was performed for two dependent variables - trial length, and number of correct responses per session. The latter variable was not directly recorded in the data; rather it was computed during the analysis.

The SAS/GLM procedure (Cody and Smith, 1991) was used to perform the analyses of variance. When the responses from all subjects were combined for the period of time when the ship motion sensing device was co-located with the computer hosting the human performance software, there were 1,642 observations. This data set contained 33 levels of vertical acceleration, ranging from 0.248 to 0.423 metres per second squared.

No significance was found for the first test: vertical acceleration vs trial time. However, a high level of significance ($p < 0.0001$) was found for the test of vertical acceleration vs number correct per trial. Vertical acceleration was grouped into three and five groups and the analysis redone. Groups were of equal size and the number of responses per group (in the five-group analysis) varied from 128 to 536. Figure 1 provides a graph of the mean fraction correct for each group in the five-group case. A maximum variation in mean fraction correct of 20% was observed. The fraction correct decreases to a minimum in group three and then increases again. The differences are statistically significant.

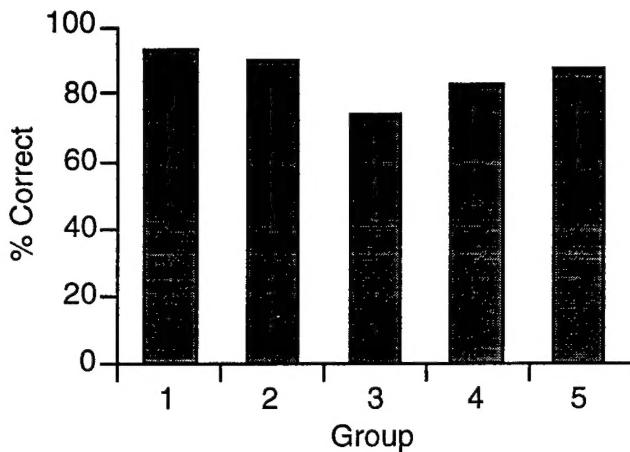


Figure 1 - Fraction Correct by Grouped Vertical Acceleration

Discussion

The primary objective for this field trial was the collection of sonar data; therefore, the use of the space available for research purposes and the cruise pattern of the ship were determined by the needs of the underwater acoustics section. From the perspective of human performance research, the purpose of this study was largely a pilot project to assess the feasibility of various types of human performance experimentation at sea. As a result, the majority of this section has a "lessons learned" flavour, which will be of importance in the planning of a future sea trial.

One of the primary logistical concerns that needs to be addressed for future shipboard studies is to have more of the ship's time available prior to departure. This is important for two reasons. First, there is the purely technical problem of the setup, calibration, and testing of equipment. In the present trial, the first potential day of the study was lost as details such as where to mount cameras and set up computers were addressed. The second reason pre-departure time is crucial concerns the cognitive test battery. Subjects in the current study had no experience with the tests prior to experimental sessions, so the lack of baseline data and the inevitable presence of a learning curve is confounded with any subjective feelings of sea-sickness that may have influenced results.

Obtaining subject participation was a continual problem during the Quest study. Most of the crew were not interested in taking part, and many who did participate were not reliable in showing up every day. Ideally, future studies would employ a group of volunteers who have no duties beyond being subjects. These people would spend at least two days on board the ship while in port, training on all tasks until performance is stable. As well as providing baseline data and thus establishing a meaningful basis for comparison with experimental sessions, the scheduling of tasks could also be controlled resulting in more productive time being available at sea.

One of the motion detectors brought on board for the human performance testing was unfortunately not functioning right from the start of the trial. Since it was deemed most important for the postural stability testing the sensor was in the forward lab for days one through six for the static testing, and moved to the aft lab where the dynamic postural tests and the cognitive task battery were conducted on days seven through eleven. Since ship motion can vary to a large extent in different parts of the ship, correlating motion with cognitive data could be accomplished only for the latter part of the trial, further limiting the amount of data available for analysis.¹ This problem could have been detected and rectified had pre-departure ship time been available. It is clear that the need for thorough checking and calibration of all equipment is crucial for sea trials where technical support is not likely to be readily available once the testing has begun.

Table I gives a sample of the reduced ship motion data supplied by DREA. The period covered is from 8:15 am, March 13, 1995 through 5:11 pm of the same day. The ship motion data should provide one or more choices for an independent variable against which to measure performance on the cognitive test battery. Griffin, (1990), reports on page 300 that "... pitch and roll motion, either alone or in combination with vertical oscillation, had no systematic effect on the incidence of motion sickness." On the same page it is suggested that MSI is consistent with the magnitude of vertical motion. However, the preferred measure is in units of Hz (see below).

Ships at sea move according to complex, but repeating relations. Studies have shown that motion frequencies are particularly important in the incidence of sickness (e.g. Griffin, 1990). Vertical motion frequencies in the range of 0.167 Hz to 0.333 Hz

¹With known ship geometry, it is possible to transform the motion data collected during days one through six; however, the effort involved was unwarranted for this pilot trial.

have been found to induce sickness at a high rate (*Ibid*, p. 298); furthermore the principal vertical acceleration of most ships is around 0.2Hz - where sensitivity is close to the maximum (*Ibid*, p.313).

The data reduction interval provides additional difficulties in this case. Inspection of the data reveals that the shortest interval between RMS means is approximately fifteen minutes. The duration of the cognitive test battery was observed to be approximately five minutes for many subjects, indicating that the data reduction interval for the ship motion data was too large.

Table I: Sample Processed Ship Motion Data

Elapsed Time (days)	Pitch Motion (deg/sec)	Roll Motion (deg/sec)	Vertical Acceleration (m/s ²)
7.344	0.608	1.595	0.311
7.362	0.578	0.602	0.401
7.424	0.528	0.848	0.287
7.445	0.708	0.680	0.376
7.466	0.693	0.604	0.367
7.487	0.650	1.123	0.336
7.508	0.623	0.59	0.329
7.529	0.626	0.657	0.318
7.549	0.423	0.767	0.252
7.570	0.482	0.616	0.260
7.591	0.459	0.679	0.259
7.612	0.481	0.678	0.248
7.633	0.556	0.623	0.353
7.654	0.517	0.635	0.318
7.674	0.490	0.878	0.282
7.695	0.735	0.912	0.354
7.716	0.702	0.675	0.324

The problem of data reduction interval has already been noted. A related difficulty encountered in this trial was the recording of timings. The task software recorded trial times on the MicroSlate computer. However, built-in PC clocks are notoriously inaccurate and can gain or lose minutes a day. In this trial, no calibration was done between the PC's built-in clock and the timings from the ship motion recorder. Since the accuracy of the PC's clock was unknown, it was decided to use the

session start times recorded by the experimenter to identify the most appropriate ship motion sample.

Ideally, there should be one set of data recorded per trial. For a future trial, it is desirable to develop a PC-based system that can request a ship-motion sample at the end of each trial, and record the motion measurements in the same data file as the performance measurements. A single clock should be used, and if it must be the one built in to the PC, it should be calibrated daily. A hand-held GPS unit could be used for calibration, since the GPS satellites maintain and transmit highly accurate timing information.

The SRT, STM, and LRT tasks were developed and tested using keyboard input. The MicroSlate computer version uses only a non-active touch pen for response input. Baseline performance data has not been collected for these versions of the tasks, and therefore the required amount of experience to overcome the learning curve effect has not been established.

Conclusion and Recommendations

The pilot trial for collecting human performance data at sea highlighted the difficulties in a task of this nature. A new implementation of a cognitive test battery was brought to a new environment and the software and its host computer functioned well. A rudimentary look at the data collected indicates that the measures can vary significantly (20% variation in mean fraction correct observed); however, the interpretation of the variation is unclear. It was not possible to associate increasing errors with increasing vertical acceleration. Response time did not show significance.

It is recommended that:

- The cognitive test battery used in this sea trial be used in a subsequent, formal study of the effects of ship motion on human performance.
- The trial should, if possible, be dedicated to the collection of human performance data - or at least have that goal as its primary objective.

- The formal study should be planned so that subjects are available who are participating in the experiment as their primary activity on board.
- Subjects should be fully trained in the use of the test battery before the ship departs, and baseline data should be collected from the subjects ashore a day or two before departure, and after return.
- Appropriate amounts of laboratory space should be available.
- If possible, the trial should be planned for a time period when significant changes in sea state are likely over a period of a few days. Low sea state conditions might be simulated by cruising in a bay or harbour area (e.g. Bedford Basin) for part of the trial.
- The data collection software should be improved to communicate directly with a ship motion sensor. The latter device may also need to be redesigned to provide direct, real-time output to a PC.
- Vertical motion should be recorded in units of Hz, and the software should be capable of requesting an RMS sample co-incident with the trial times.
- A formal method for recording sea states should be developed. Sea state provides an alternate choice for an independent variable against which performance can be measured.
- The database created by the cognitive test software should be improved.
- Additional human performance tasks be investigated for use on-board ship. While the STM, SRT, and LRT tasks are simple, proven tests, there is room for human performance measurements which record speed and accuracy data for more ship-related functions - for example, navigation. A task which identifies different levels of effectiveness in decision making would also be of benefit. Revisiting previous work on vigilance tasks would be beneficial.

- It is possible that a one or two week sea trial is insufficient time to collect human performance data from which generalizations can be made. It is recommended that a test battery be developed which could be taken to sea by the Canadian navy on long duration deployments. Such a task set could be incorporated into a computer-based training module or a computer-game.

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